SENSITIVITY ANALYSIS OF FAULT LOCATORS IN POWER DISTRIBUTION SYSTEMS CONSIDERING DISTRIBUTED GENERATION

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ABSTRACT

This paper presents the methodology to perform sensitivity analysis for impedance-based fault location methods, considering power distribution systems and the presence of distributed generation. The proposed methodology helps to determine the power distribution system model parameters, which significantly affect the fault locator performance. Having identified such parameters, the next step is to perform analysis and compensations aimed to develop more robust locators. As result of the proposed methodology, a set of critical parameters of the power system model is here identified.

INTRODUCTION

Quality power electrical is an important aspect in power system operation, due the requirements normally associated to the continuity indexes. One of the current applied strategies aimed to maintain the continuity indexes, are associated to fault location [1][2]. By an opportune fault location, actions as maintenance, restoration and reconfiguration of the affected power system are significantly improved.

In the case of power distribution systems, the fault location methods are normally classified in impedance-based and knowledge-based methods [3][4][5]. This research focuses on the impedance-based applied to power distribution systems with distributed generation. These methods are used to determine the distance from the substation to the faulted node using the measurements of voltage and current at the generation sources. As these methods use the power system model parameters, are highly dependent on errors normally presented in real systems due the uncertainty associated to define the values of load, conductor resistance and system capacitance and impedance at the fault time instant.

The validation of fault location methods has been performed using different methodologies. Initially, the methods consist on a simulation of several scenarios that varies the fault location and the fault resistance, however aspects associates to the power system parameters were not considered [4]. Several approaches perform the same evaluation of the fault locator as previously presented [1][2][3].

One of the alternatives to consider these parameters is the development of an extensive simulation tool to create a fault database in a power system by considering variations on load size, and values of fault resistance, fault location, conductor resistance, system admittance and capacitance, line arrangement, among others [6].

By using the extensive data simulation a methodology to perform a sensitivity analysis for impedance based fault location methods applied to radial and also non-radial power distribution systems, under of hundreds of different operating conditions. The last power system considers the presence of distributed generation.

The sensitivity analysis determines which of the modelling parameters that most affect the performance of the locator. These have to be deeply analysed to determine the best way to improve the locator. This strategy allows developing more robust fault location methods.

This paper is divided into the following sections; section two presents the theoretical aspects; section three presents the proposed sensitivity analysis methodology; section four is devoted to show the obtained results and finally, at the last section the main conclusions of this research are highlighted.

BASICS THEORETICAL ASPECTS

This section is devoted to present the basic aspect of the theoretical foundation used to develop the sensitivity analysis methodology here proposed. A deep analysis or explanation are out of the scope of this paper but can be obtained at the provided references.

Sensitivity analysis

The sensitivity analysis help to determine the input parameters that most influence the output variability, by the evaluation of different scenarios that may occur in the daily operation of the power system. This analysis is performed to represent real-life circumstances such as erroneous measurements, lack of information or uncertainty of some input parameters.

Sensitivity analysis has three main stages: the definition of the sampling technique, the model evaluation, and performing of technical sensitivity. These steps allow identifying the variables that most affect the fault location methods [7].

Latin Hypercube sampling

The defined sampling technique is the Latin hypercube. This technique generates a small set of data that completely represents the total data search space, reducing the computational cost. This sampling technique has the main feature that is independent of the model being analysed [8].

The input data of the sampling technique consist of a number of variables s to be changed and n is the number of points to be evaluated. This technique generates an n by s matrix with values between 0 and 1, where each row represents a point to be evaluated and the columns represent the coordinates of that point [9] [10].

Tabu search

Tabu is a Meta heuristic used here to improve the sampling process performed by Latin hypercube. This technique uses the concept of adaptive memory, so the movements are defined as "Tabu movements" to avoid returned to areas that had already been visited, allowing it to escape from local optima [10].

Regression Analysis

Regression analysis is a statistical process that determines the input variables that most affect the output. Through this analysis, the coefficients called Beta coefficients are obtained. As high is the Beta coefficient, most important is the associated parameter (input) on the behaviour of the fault locator (output). The Beta coefficients are calculated using (1), where the absolute value of this coefficient indicates the importance of the variable [7].

$$\beta_j = \frac{b_j \, Sx_j}{Sy} \tag{1}$$

To calculate the variables in (1), the Equation 2, 3 and 4 are required. Where, x is the uncertainty matrix obtained from Latin hypercube, y is the vector of results and n is the number of evaluated points.

$$b_j = (x^T x)^{-1} x^T y \tag{2}$$

$$Sx_j = \sqrt{\sum_{k=1}^{n} \frac{(x_{kj} - \bar{x}_j)^2}{n-1}} \tag{3}$$

$$Sy = \sqrt{\sum_{k=1}^{n} \frac{(y_k - \bar{y})^2}{n-1}} \tag{4}$$

PROPOSED METHODOLOGY

The general scheme of the proposed methodology of sensitivity analysis of impedance-based fault locator for power distribution systems considering distributed generation is shown in Figure 1. Sensitivity analysis is performed by a cooperative strategy between ATP and MATLAB. ATP is used as modelling and simulation software and MATLAB is used as software for handling the information.

The first step of the proposed methodology consists in sampling the total space using Latin hypercube. This technique has as input data, the variables n and s. In the specific case of the sensitivity analysis, n represents the number of operating states in which the power system is analysed and s represents the considered power system modelling parameters. The parameters considered in this paper are the magnitude and unbalance of the generation sources, the magnitude of the load, the power factor, the line length and the system frequency. Each parameter is varied within a certain range to represent changes or different operational states of a real distribution system.

Latin hypercube generates an uncertainty matrix, n by s, where each row indicates an operating state of system and each column indicates the percentage change of each parameter.

To complement this sampling technique is used a Tabu, as previously described, to maximize the distance between samples and then ensure the uniform distribution of the sampled space.

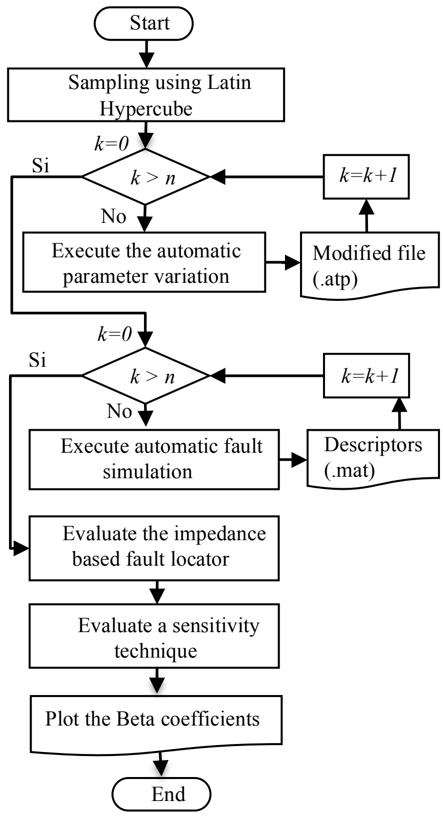

Fig. 1. Sensitivity analysis methodology

Having defined the operating conditions the automatic parameter variation is performed, by using the base ATP card that describes the nominal power system and the uncertainty matrix [8]. As result of this step, n modified ATP cards are obtained and each card represents a case that may occur in the daily operation of the distribution power system.

The modified cards are the input to the automatic fault simulation tool. Each card or power system operating condition is simulated considering faults at different fault location and also different fault resistances, to obtain the values of voltage and current, during the pre-fault and fault steady states at the generation sources [6].

Subsequently, the fault database of measurements of voltage and current are used to perform an extensive evaluation of the impedance based fault location method, which consider the presence of distributed generation. After evaluating the method, the error of locator is obtained by comparing the real distance of the fault and the distance obtained by the impedance based fault locator [5].

Finally, the proposed methodology generates the Beta coefficients through the regression analysis technique. This statistical process uses the uncertainty matrix and the errors obtained by the impedance based fault locator to calculate Beta coefficients. Each coefficient indicates the importance of the modelling parameters on the fault locator. The coefficients are presented using graphs for an easy analysis.

TEST AND RESULTS

The methodology above presented is applied to a modification of the IEEE 34-node system with distributed generation, which is obtained from the "Distribution System Analysis Subcommittee" of the "Institute of Electrical and Electronics Engineers" [12]. The power system was simulated in ATP and as is shown in Figure 2 and contains a distributed source. The sensitivity analysis tool was validated using one extension to consider three phase faults of the impedance-based method presented in [12]. Faults were located at the longest radial feeder, which is indicated in figure 2 by the dashed lines. The tests were performed considering fault resistances of 0 Ω to 40 Ω [13].

Sensitivity analysis is performed for 200 operating conditions and varying the six parameters in the range shown in Table 1. Considering the operator experience and national normative, the range variation was defined.

Additionally, the sensitivity analysis tool, which the simplified interface is presented in figure 3, has the working folder, ATP card of the analysed power system and the number of operating states to be analysed, among others. In addition, the parameters to be modified and their respective ranges are defined.

The results of the sensitivity analysis are shown on graph, where the vertical axis represents the value of the Beta coefficients and the horizontal axis represents the nodes where faults are analysed.

A total of 16000 single-phase faults and the same amount of three-phase faults were used in this analysis.

Single-phase faults

In figure 4, the results of the average Beta coefficients for single faults are presented. The result shows how the magnitude of the load is one of the parameters that most affect the fault locator. As a consequence a good estimation strategy of the load magnitude have to be developed as a first strategy aimed to improve the fault locator performance.

An additional parameter analysed is the line length. This parameter has a major influence in the most distant nodes from the main power substation, because the modelled admittance and impedance parameters are not accurate, therefore an error is accumulated along the radial. The real systems sometimes have additional measures to the main power substation. These measures can be used to decrease the error.

The frequency is the other parameter that has a significant influence. This parameter is varied to represent measurement errors that appear in the databases of the utilities. In this case, the results show a random behaviour.

Finally, the figure shows that the unbalance of the phases of the generation sources and the load power factor are the parameters that have the lowest affect in the fault locator performance.

Three-phase faults

An additional result is presented in figure 5, in the case of three phase faults at the same feeder.

As it is presented, the results are similar to those obtained in the case of single-phase faults.

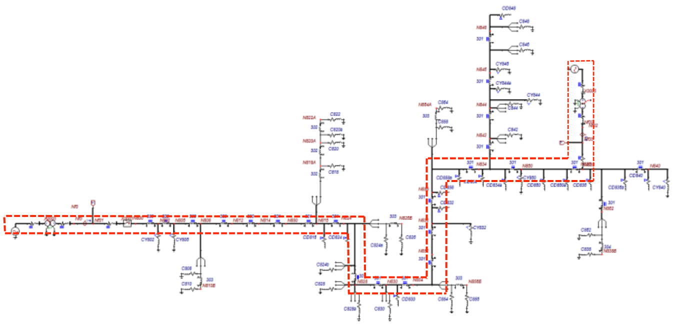

Fig. 2. IEEE 34-node power distribution system

Table 1: Uncertainty ranges of the parameters

Modelling parameters	Variation range	
	Minimum	Maximum
Voltage source magnitude	0.95 p.u	1.10 p.u
Voltage source unbalance	-3.4 °	3.4°
Magnitude system load	10%	150%
Power factor	-0.02	0.02
Line length	95%	105%
Frequency	59.8 Hz	60.2 Hz

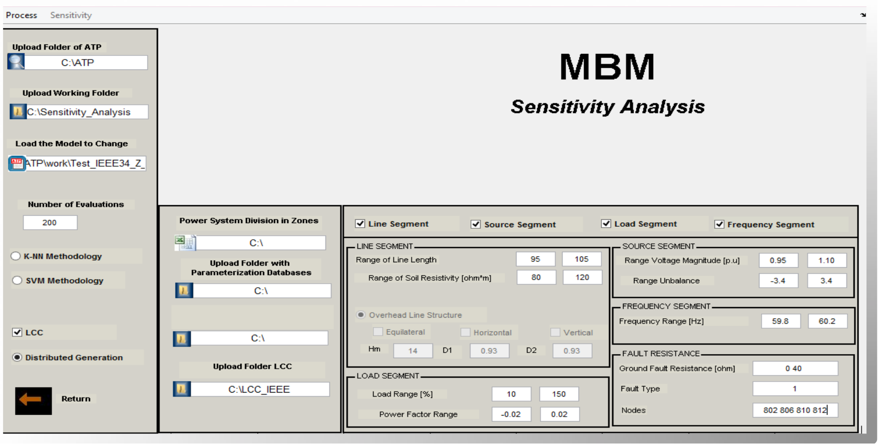

Fig. 3. Main working interface of the sensitivity analysis tool

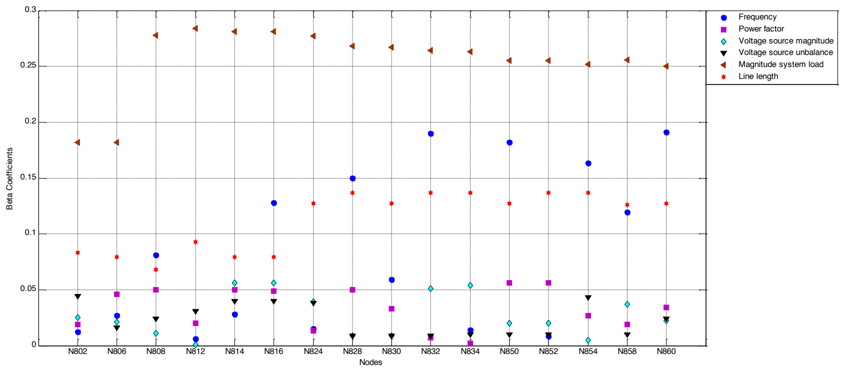

Fig. 4. Results of the sensitivity analysis for single phase fault (A-g)

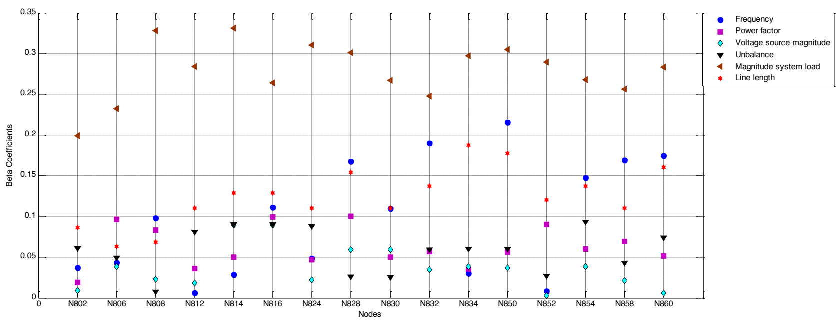

Fig. 5. Results of the sensitivity analysis for three phase faults (A-B-C-g)

CONCLUSIONS

The sensitivity analysis methodology helps to identify the modelling parameters of the power distribution system, which have a significant effect on the fault locator performance. According to the obtained results for a single-phase and three phase faults, considering fault resistances form 0 and 40 Ω the most influential parameter is the load size. Parameters as the line length and frequency also influence the fault locator performance. Then, the next step in the improving process aimed to obtain a really robust fault locator is to develop strategies for the adequate estimation of the load size at any time, and also adequately verify the line length along the analysed feeder.

As it was demonstrated, the proposed sensitivity analysis methodology is really helpful in the fault locator improving process, by the identification of those influential parameters.

Finally, robust fault locators allow fast restoration of the power system, ensuring high levels of the power supply continuity indexes.

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